Fast Tuner R&D for RIA*

Presentation for the RIA R&D Workshop

August 26-28, 2003

Bethesda, MD

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This work has been performed under the auspices of the US DOE by UC-LLNL under contract W-7504-ENG-48

Microphonic Effects on the RIA Driver (and RIB) Linacs Strongly Influence the RF Design and Cost

- RIA is not like other linacs where beam loading is comparable to the microphonic detuning
- The microphonic control window for RIA is expected to be on the order of 50-150 Hz, which is larger than the beam loaded bandwidth
- Light beam loading on the Driver and RIB linacs necessitates that microphonic detuning of the SRF cavities be addressed
  - Heavy ion machines have limited and widely varying beam currents across species driven primarily by ion source considerations
  - Stable operation on species and rapidly retuning the machine are important for customer satisfaction

linear accelerator	operating frequency (MHz)	loaded Q	bandwidth (Hz)
CEBAF/Jefferson Lab	1497	2.2×10^6	680
SNS/ORNL	805	7.0×10^5	1,150
APT design/LANL	700	2.2×10^5	3,182
RIA – 115 MHz – U beam	115	8.7×10^6	13
RIA – 345 MHz – U beam	345	1.3×10^7	27
RIA – 805 MHz – U beam	805	8.3×10^7	1

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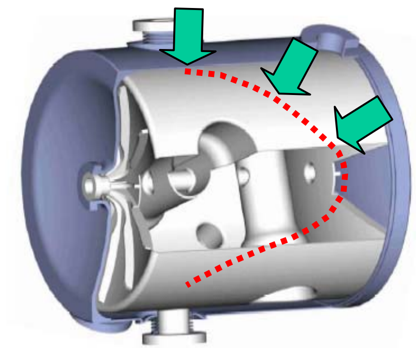
SRF Cavities are Prone to Microphonic Detuning



Superconducting 345 MHz Two-Spoke Cavity for RIA - K. W. Shepard et al, PAC 2003

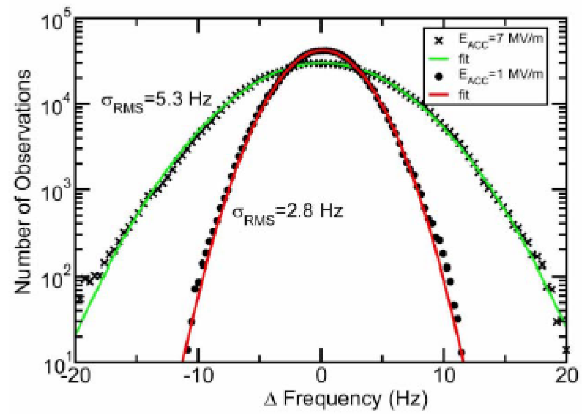


Figure 2. Probability density for double spoke eigenfrequency deviations for cw operation at E_{ACC}=7 MV/m (broad curve) and E_{ACC}=1 MV/m (narrow curve).

Microphonics Measurements in SRF Cavities for RIA
M. Kelley et al, PAC 2003

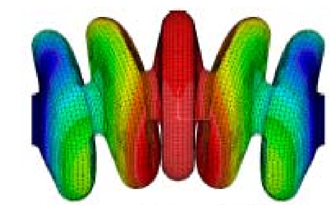


Figure 5: Lowest Mode of β = 0.61 5-Cell Cavity

Table 5: Cavity Structural Frequencies of 5-Cell Cavities

CAVITY	WALL THICK mm	UN-STIFFENED CAVITY LOWEST FREQUENCY Hz	STIFFENED CAVITY LOWEST FREQUENCY Hz
β = 0.48	5.0	47.	181.
β = 0.61	4.0	40.	217.
β = 0.77	4.0	37.	251.

Table 6: Cavity Structural Frequencies of 7-Cell Cavities

CAVITY	WALL THICK mm	UN-STIFFENED CAVITY LOWEST FREQUENCY Hz	STIFFENED CAVITY LOWEST FREQUENCY Hz
β = 0.48	5.0	27.	130.
β = 0.61	4.0	22.	130.
β = 0.77	4.0	20.	142.

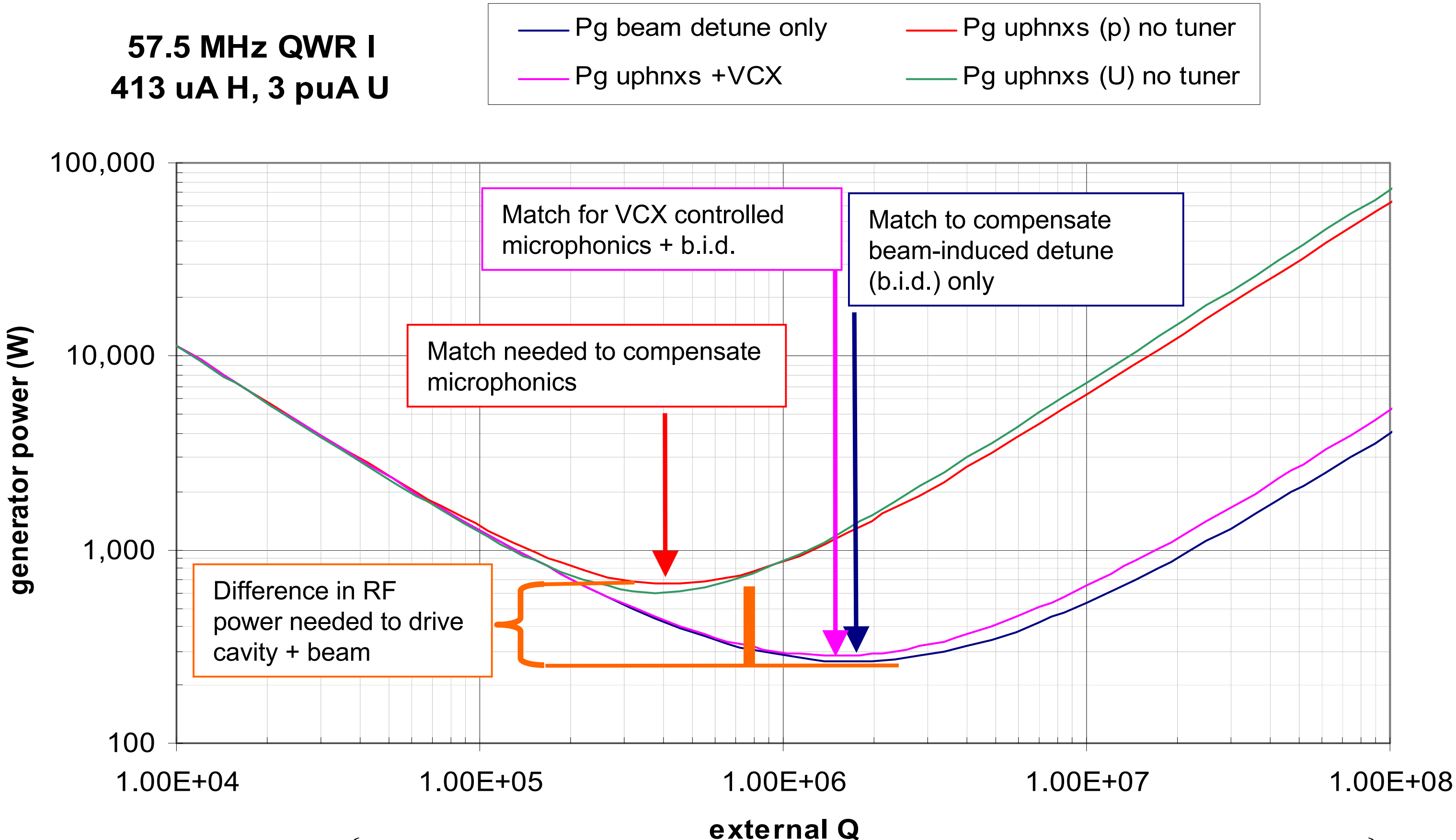
Past experiments [7] have shown good agreement of measured mechanical resonant frequencies with the predicted values. It is important to note that the analyses were run for simple cavities; there were no beam tubes, power couplers, HOM couplers, etc. included. In addition, there is no consideration of the stiffness of the cavity support structure. Inclusion of any or all of these items will reduce the mechanical resonant frequencies. Thus, the frequencies listed in Tables 5 and 6 must be regarded

Structural Analysis of Superconducting Accelerator Cavities
D. Schrage, XX Linac Conference, Monterey, CA

- Sheet metal construction combined with small (beam) matched-coupling bandwidths creates an RF control challenge
- This is exacerbated by 4.2 K operation

"Idealized" Generator Power Related to a Q_x Setpoint for a Fixed Beam Current

57.5 MHz QWR I
413 uA H, 3 puA U



$$P_{gen} = \frac{P_c}{4}\left\{\frac{2I_oR_a}{V_c}\left[\left(1+\frac{Q_x}{Q_0}\right)\cos(\phi)-2Q_x\delta\sin(\phi)\right]+\left[\frac{(Q_0+Q_x)^2+4(Q_0Q_x\delta)^2}{Q_0Q_x}\right]+\left(\frac{I_oR_a}{V_c}\right)^2\frac{Q_x}{Q_0}\right\}$$

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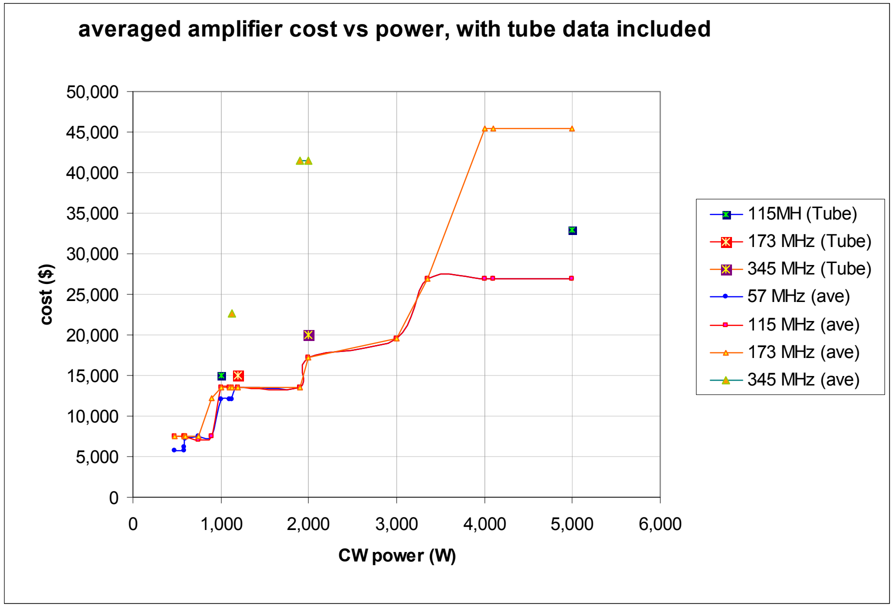
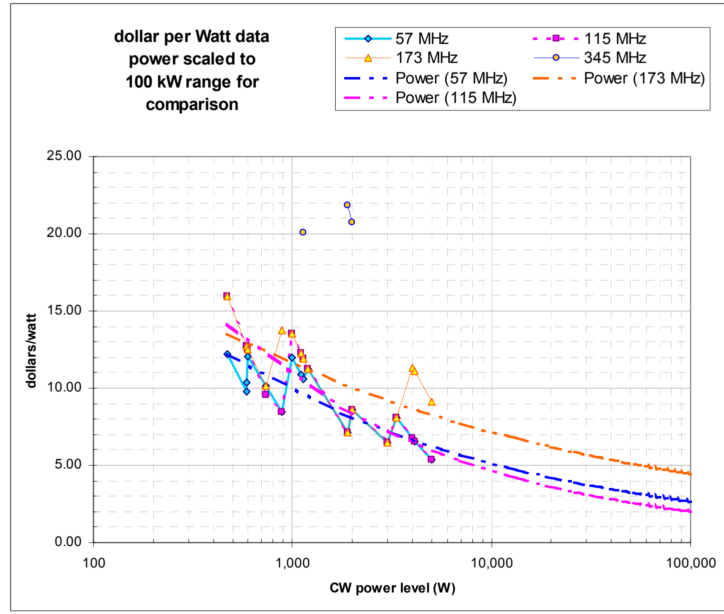
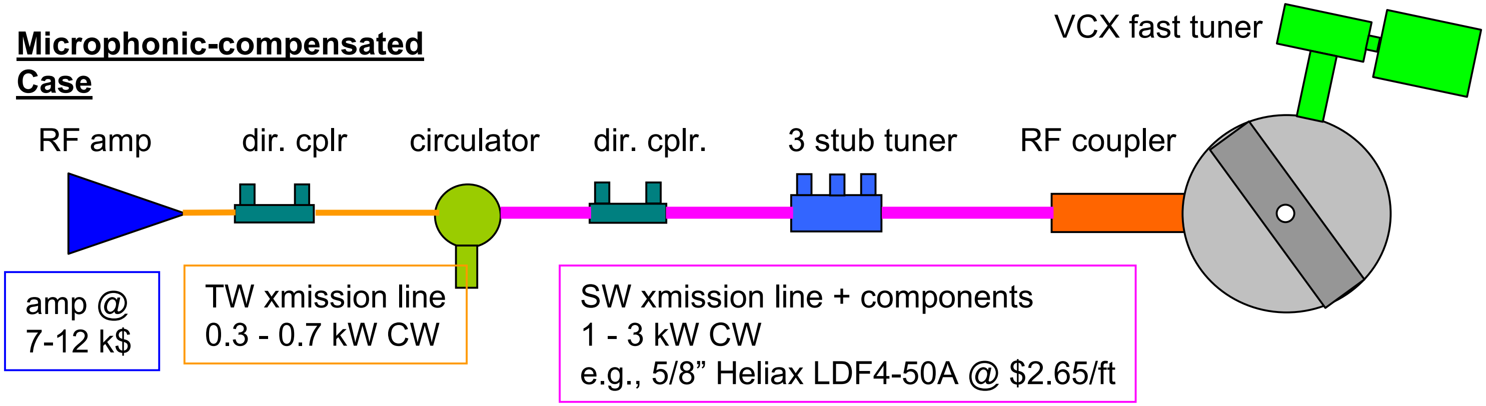
Variations in RF Power Costs Can Lead to Wide-Ranging Estimates

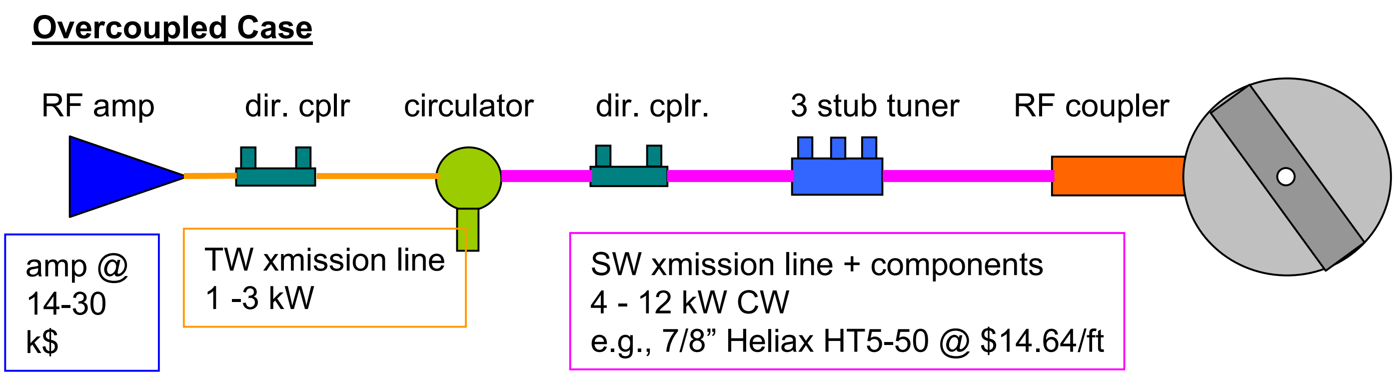




Cost data at low RF power levels shows "staircasing" effect, suggesting system engineering is important for cost-optimizing the design

Two RF Deliver System Concepts Were Developed to Compare Costs





Comparative Summary of Overcoupled and VCX Fast Tuned Cases Demonstrate Impact

	------- Overcoupled Case ------		- VCX Tuner Compensated -	
cavity type	**installed**	**section**	**installed**	**section**
	RF power	**cost**	**RF power**	**cost**
low β	**(W)**	**(k$)**	**(W)**	**(k$)**
57.5	160,000	2,155	30,000	1,160
115	225,000	2,424	45,000	1,576
172.5	520,000	7,522	104,000	3,642
345	160,000	5,508	160,000	5,098
low β subtotal	**1,065,000**	**17,609**	**339,000**	**11,476**
high β				
805 - 0.49	960,000	7,749	240,000	5,039
805 - 0.61	1,920,000	12,412	320,000	8,140
805 - 0.81	1,400,000	7,066	280,000	3,561
high β subtotal	**4,280,000**	**27,227**	**840,000**	**16,740**
LN lines low β				**175**
LN lines hi β				**225**
linac totals	**5,345,000**	**44,836**	**1,179,000**	**28,616**

Low β cost savings: 6.1 M$

High β cost savings: 10.5 M$

- Reduced cost primarily due to the factor of 3-5 less installed RF power, smaller RF couplers, transmission lines, and components which more than offsets the cost of the tuner and pulser.

- Costs include estimates for running cryogenic LN lines in the tunnel. It does *not* include the costs for the LN cryoplant capacity needed.

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Approaches to Compensate Microphonic Detuning

- Microphonic detuning is more a cost and implementation challenge than a technical "show stopper"
- It comes down to where the effort and resources are placed:
  - Overcoupling: costly, wastes RF, but is effective
  - VCX fast tuning: efficient, needs further development
  - Piezoelectric, Magnetostrictive: need further investigation
  - Cavity stiffening: mechanical engineering design and cost challenge
- Based on the operational agility and the effectiveness of the VCX fast tuner on the ATLAS , development in this area is being pursued in the baseline design for RIA
  - Phase I: extend ATLAS design to 345 MHz using distributed element model
  - Phase II: explore applicability to elliptical or multi-spoke cavities with much higher stored energy and frequency

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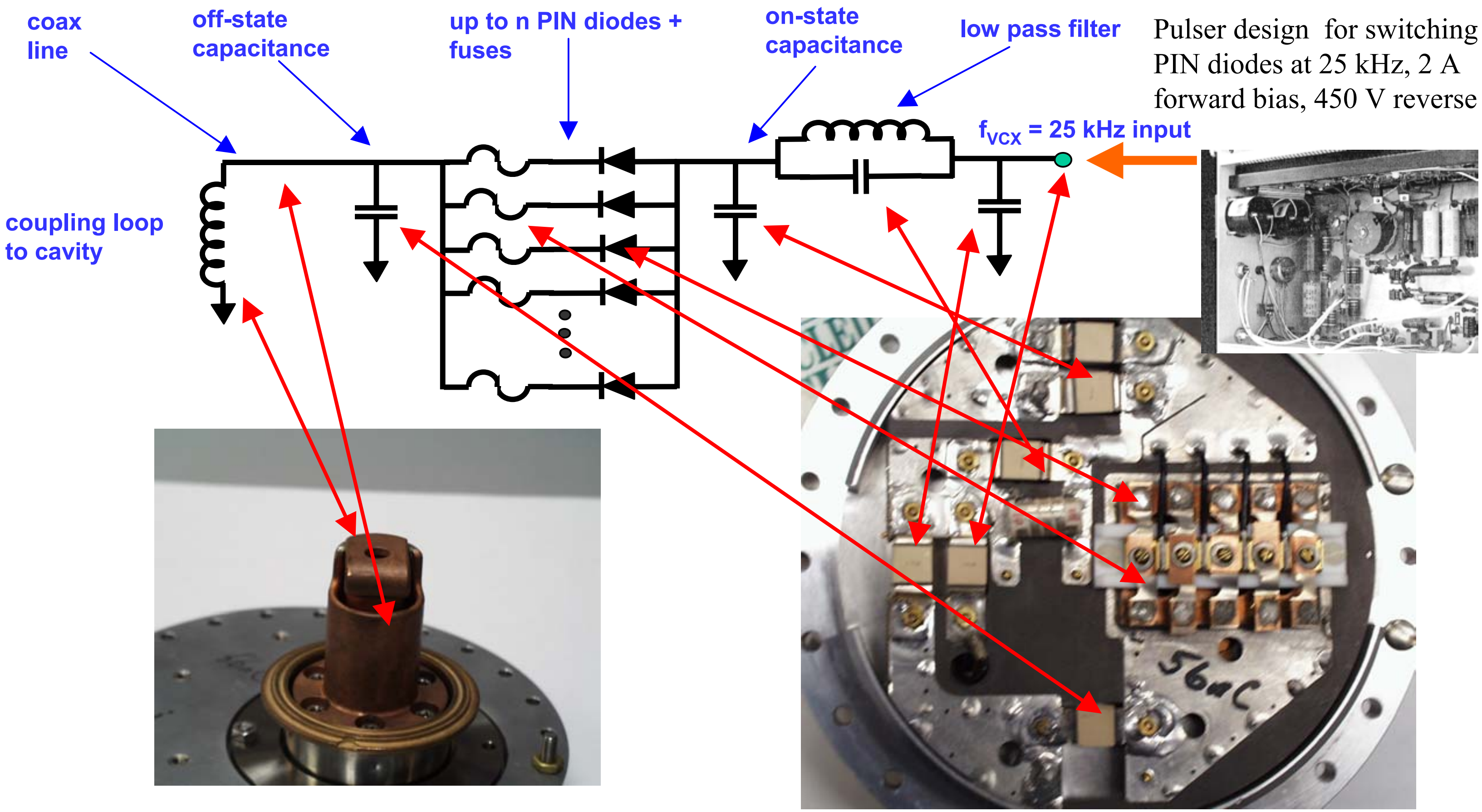
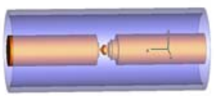
VCX Fast Tuners have been Successfully Deployed on ATLAS for 20+ Years



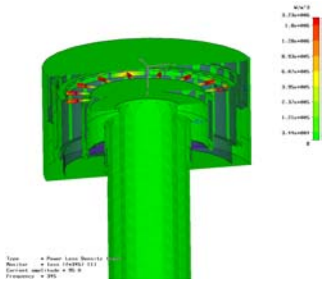
Pulser design for switching the PIN diodes at 25 kHz, 2 A forward bias, 450 V reverse bias

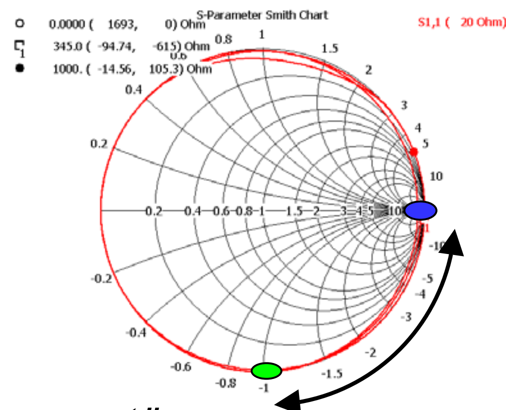
VCX lumped-circuit design used on ATLAS at 48.5 - 97 MHz, circuit area shown is flooded with LN

Fast Tuner R&D Work Has Spanned RF Coupler Design and Advancing the VCX Concept for Higher Frequency and Power



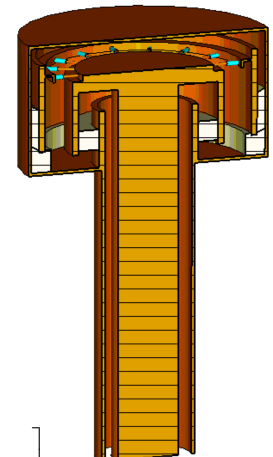
lumped elements

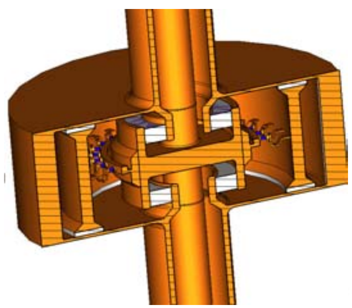


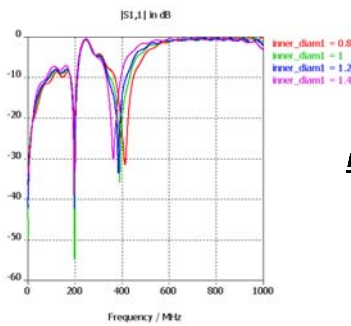


non-resonant line

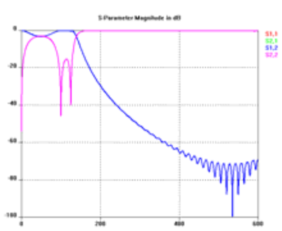
$$\Delta f = \frac{V^2_{loop}}{8\pi U}\left[\frac{1}{\mathrm{Im}(Z_{on})} - \frac{1}{\mathrm{Im}(Z_{off})}\right]$$

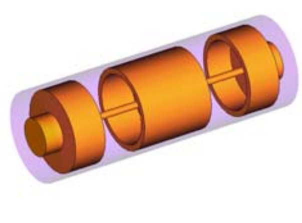




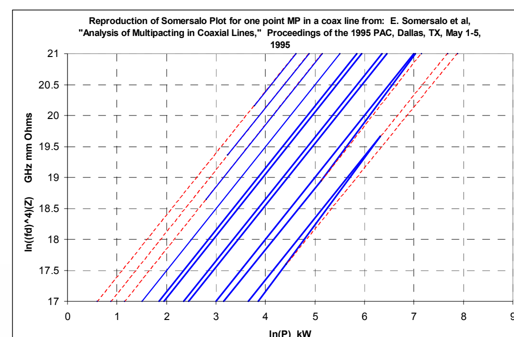


resonant bandpass window

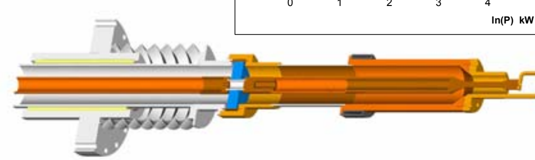




distributed low pass filter



RF power coupler



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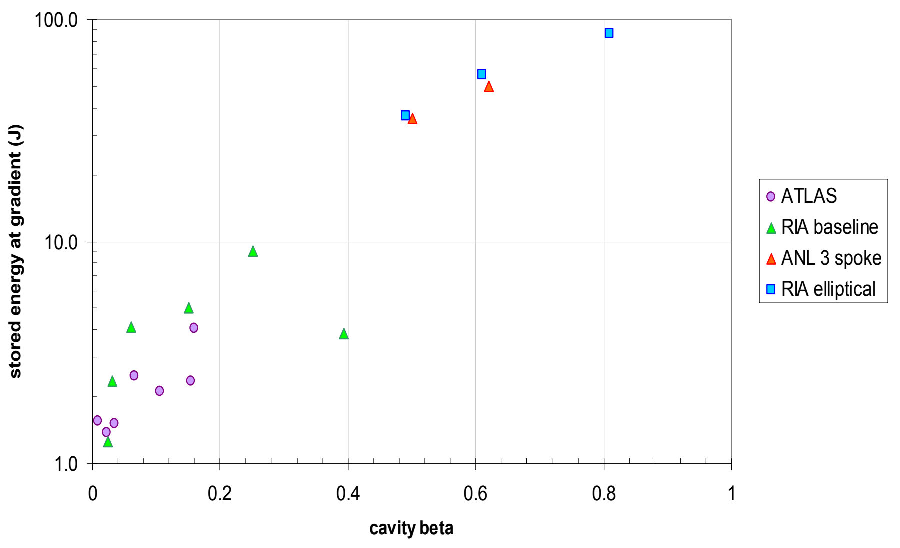
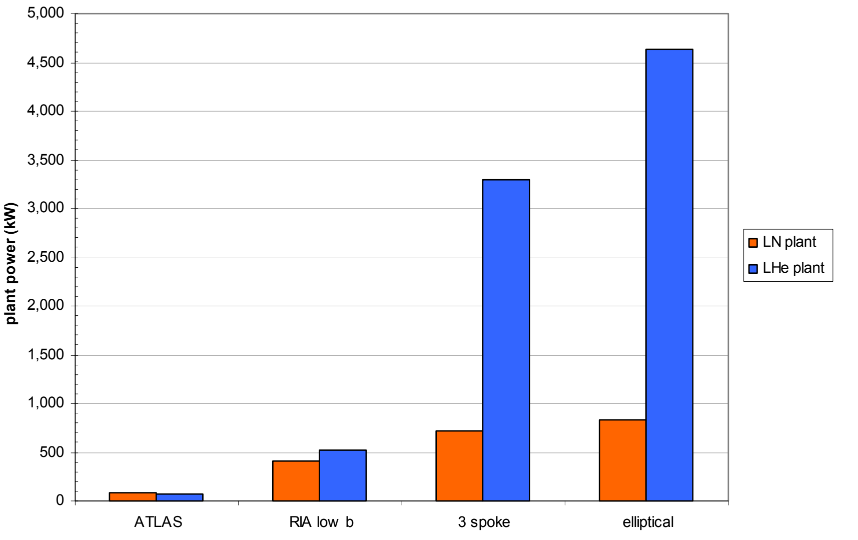
System Studies are Underway to Evaluate the Applicability of VCX to the Higher Stored Energy Cavities of RIA





Comparing cavity stored energy at gradient shows that ATLAS data on VCX is applicable for the low β portion of the linac.

A concern is whether the higher stored energy in the 3 spoke cavity will make the cryogenic plant size excessive.
A preliminary assessment shows it to be reasonable (but not small).

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Further R&D Needed on Fast Tuning

- Perform a system evaluation on the three major fast tuning approaches, incorporating data from ANL and MSU
- Iterate fast tuner technology with latest linac designs - what is the best fast tuner approach for RIA?
- Continue developing a VCX fast tuner prototype for testing
- Develop full conceptual designs for the RF component and power delivery systems for the RIA driver and RIB linacs - optimize for (low) cost with performance
- Establish interfaces with LLRF control activities

Conclusions

- The light beam loading on RIA complicates RF control of the SRF cavities in the presence of microphonics
- Preliminary RF system and cost studies indicate that using some form of fast tuning system could result in substantial cost savings over overcoupling
- The VCX fast tuner concept developed at Argonne for ATLAS demonstrates the effectiveness of this approach
- R&D work is advancing on evolving a distributed-element VCX concept that should be extendable to higher frequency (345 MHz) and higher switched-power levels

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